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(54) **Nuclear radiation apparatus and method for dynamically measuring density of test materials during compaction.**

(57) The present invention provides an apparatus and method for dynamically measuring the density of soil, asphaltic material and the like during the compaction of the material. The gauge (20) includes a nuclear radiation source (31) and a nuclear radiation detector means (32) which are mounted in spaced relation from the surface of the test material to form an air gap therebetween. The gauge also includes means for measuring the size of the air gap between the test material and the source and detector system, and means to compensate for the effect of the size of the air gap to thereby obtain the density of the test material.

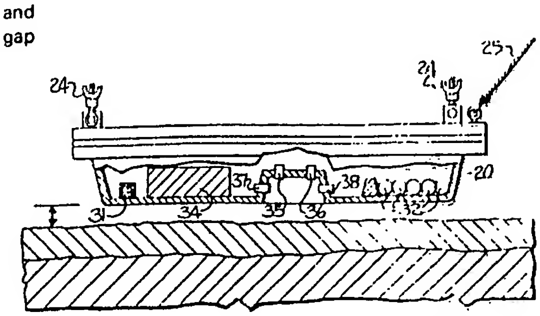

Fig. 5

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NUCLEAR RADIATION APPARATUS AND METHOD FOR DYNAMICALLY MEASURING DENSITY OF TEST MATERIALS DURING COMPACTION

Field and Background of the Invention

The present invention relates to an apparatus and method for determining the density of test materials, and more particularly to a nuclear radiation measurement apparatus and method for measuring the density of soil, asphaltic materials and the like during movement of the radiation measurement apparatus across the surface of the material which is undergoing measurement.

Nuclear radiation gauges for determining the density of soil and asphaltic materials are well-known, as described for example in U.S. Patent 2,781,453. Such gauges employ the phenomenon of Compton scattering of gamma rays and are known by those skilled in the art as "scatter" gauges.

Such gauges typically take the form of a hand held portable instrument which is positioned on the surface of the test material for a predetermined period of time while backscattered radiation is counted to obtain a density reading. Devices of this type have been widely used and well accepted in the industry for obtaining rapid non-destructive density measurements of the test material. The density gauges are particularly useful in determining the degree of compaction of soil or asphalt during the construction of roadbeds and pavement surfaces, in which heavy rollers or compactors are

rolled back and forth across the surface and density readings are made periodically using the portable stationary nuclear density gauges of the type described above.

It has been recognized that it would be quite desirable to obtain a readout of density continuously during the compaction operation, rather than periodic spot density readings. This approach would give an average or integrated density reading over a large area rather than an instantaneous spot reading, and would also make it possible to more rapidly respond to changes in the density readouts during the compaction operation. To this end, several movable, dynamically reading nuclear density gauges have been proposed. One such gauge is in the form of a wheeled unit and employs a pair of small cylindrical rollers as wheels with a nuclear source and detector mounted between the rolls in a suspended, non-contacting relationship with the underlying test surface. The gauge rides along the pavement surface and may be connected to and pulled by a pavement compactor vehicle. Another such gauge, described in published European Patent Application 108,845, has the nuclear radiation source and detector mounted inside of a cylindrical roller, and the roller may be manually pushed along the pavement surface or propelled therealong by connecting it to a pavement compactor vehicle.

Both of these gauges assume a constant spacing (air gap) between the source/detector system and the underlying pavement surface. However, the density reading obtained from a backscatter gauge through an air gap is quite sensitive to variations in the size of the gap. During operation, any buildup of asphalt on the rollers will increase the effective diameter of the rollers and alter the size of the air gap between the

source/detector system and the surface of the underlying test material, introducing error in the density reading.

It is an object of the present invention to provide a nuclear density measurement apparatus and method for dynamically measuring pavement density and which overcomes the above-noted disadvantages and limitations of the prior art.

Summary of the Invention

In accordance with the present invention an apparatus and method is provided in which the nuclear source/detector system is mounted for movement in spaced relation above the surface of the test material and wherein the spacing between the nuclear source/detector system and the underlying test surface is monitored as the nuclear density reading is being taken, whereby any variations in the spacing are taken into account and corrected for during the measurement.

The density measurement apparatus of the present invention broadly comprises nuclear gauge means comprising a nuclear radiation source and a nuclear radiation detector means, said source and said detector means being mounted in predetermined spaced relation from one another for emitting nuclear radiation into the test material and for detecting backscattered radiation from the test material; means for mounting the gauge means in spaced relation from the surface of the test material; means associated with said gauge means for measuring the spacing of the gauge means from the surface of the test material; and means cooperating with the detector means and with said distance measuring means for determining therefrom the density of the test material.

In accordance with the method aspects of the invention, a method is provided for measuring the density of a test material using a nuclear radiation

backscatter gauge including a nuclear radiation source and nuclear radiation detector means positioned in spaced relation to the source, and wherein the method comprises the steps of: moving the source and detector along the test material while maintaining the source and detector in spaced relation above the surface of the test material to form an air gap therebetween, obtaining a count of the photons which are backscattered to the detector by the test material, obtaining a measurement which represents the size of the air gap between the surface of the test material and the source/detector means, and correcting the count of backscattered photons based upon the obtained measurement of the air gap to compensate for the effect of the air gap and to thereby determine the density of the test material.

The method and apparatus of the present invention are especially suited for use during the compaction of soil or pavement material using a compactor vehicle, and in accordance with a further aspect of the present invention there is provided a nuclear radiation gauge which is mounted on a compactor vehicle for providing the operator of the vehicle with a readout of the density or degree of compaction during operation of the vehicle. The compactor vehicle has rollers for compaction of materials such as soil, asphalt pavement and the like and a vehicle chassis connected to the rollers. In combination with this there is provided a nuclear density gauge means for measuring the density of the material during operation of the compactor vehicle. The gauge means comprising a nuclear radiation source, nuclear radiation detector means mounted in a predetermined spaced relation from the source, and means for suspendingly mounting said source and said detector means from said vehicle chassis with the source and detector means being located in predetermined spaced

relation from the surface of the material undergoing compaction so that the source is positioned for emitting nuclear radiation into the air space beneath the gauge means and into the material and the detector means is positioned for detecting backscattered radiation from the material.

Brief Description of the Drawings

Some of the features and advantages of the invention having been stated, others will become apparent from the detailed description which follows and from the accompanying drawings, in which --

Figure 1 is a side elevational view of a compactor vehicle upon which is mounted a nuclear density gauge in accordance with the present invention;

Figure 2 is a top elevational view thereof;

Figure 3 is a perspective view thereof from the underside;

Figure 4 is a vertical sectional view through the compactor vehicle taken substantially along the line 4-4 of Figure 1 and showing the arrangements for mounting the detector unit in suspended relation a short distance above the pavement surface and for retracting the detector unit during non-use;

Figure 5 is an enlarged view of the detector unit of Figure 4, with portions of the housing thereof broken away to show the interior components; and

Figure 6 is a schematic diagram of the electronic components of the instrument.

Description of the Illustrated Embodiment

Referring now more specifically to the drawings, the reference character 10 generally indicates a compactor vehicle of the type which is conventionally used for rolling and compacting soils, paving materials and the like. The compactor vehicle includes a chassis 11 and large diameter smooth surfaced rollers 12, 13,

mounted to the chassis 11 and serving as the wheels of the compactor vehicle. As illustrated, a driver's seat 14 is located in the central portion of the vehicle chassis, and suitable controls 15 are provided to enable the driver to control the direction and speed of the vehicle. As is conventional, suitable motor means (not shown) is provided for propelling the vehicle along the pavement.

The nuclear density measurement apparatus of the present invention comprises two units, a measurement unit 20 mounted beneath the compactor vehicle and located close to the surface of the pavement, and a console unit 40 accessible to the driver's seat 14 at the top of the vehicle. The measurement unit 20 and the console unit 40 are interconnected by a cable 21. The console unit 40 includes a keyboard 41 by which the operator may control the operation of the gauge and a display 42 by which the density reading obtained by the gauge as well as other information, is communicated to the operator. The mounting of the components of the measurement apparatus in this manner makes it possible to measure the pavement density during the operation of the compactor vehicle, and to rapidly provide the operator of the vehicle with a readout of pavement density. This makes it possible for the vehicle operator to immediately know when he has completed a sufficient number of rolling passes to achieve a desired degree of compaction.

As best seen in Figure 3, means is provided on the underside of the compactor vehicle for mounting the measurement unit 20 in suspended relation a short distance, above the pavement surface. In the particular embodiment illustrated, the mounting means includes an elongate beam 22 mounted to the chassis 11 of the compactor vehicle and extending transversely thereacross.

The measurement unit is suspended from the beam 22 by three adjustable mounting brackets 24. Brackets 24 are pivotally mounted to the beam, and in turn to the measurement unit 20 to provide freedom of movement to the measurement unit in all directions. Thus in the event that the measurement unit strikes an obstruction protruding above the pavement surface, it can freely swing out of the way and then return to its normal suspended operative position. As seen in Figure 4, the mounting brackets 24 are constructed in the form of turn-buckles, to permit adjusting the height of the measurement unit and the spacing between the undersurface of the measurement unit 20 and the pavement surface. Nominally, this distance is about 1/2 inch (1.3 cm.).

As is also best seen in Figures 3 and 4, means is provided for raising the unit 20 from its lowered operative position to a retracted non-use position where the measurement unit is safe from accidental contact with obstructions and the like. In the embodiment illustrated this takes the form of a cable 25 connected to measurement unit and an actuator handle 26 associated with the cable 25 and which is positioned at a location accessible to the operator.

Prior to further discussion of the structure and operation of the gauge, it will be helpful to review some of the underlying principles of nuclear density gauge operation, particularly as applied to soil density measurement through an air gap.

The simplest, but least accurate method of measuring density involves the so-called backscatter method. To make this measurement, the source and detectors are both on the surface of the soil and gamma photons passing into the soil are scattered back to the detectors. If the soil had a density of zero, there

would be nothing to cause scattering and the number of photons backscattered to the detector would be essentially zero. As the density of the soil increases, the number of backscattered photons increase with increase in density to a point where the backscattered photons are approximately equal to the losses due to additional scattering and absorption. The quantity of backscattered photons detected then becomes an approximate negative exponential function as the count decreases with increasing density of the soil.

The backscatter method, while simple to perform, is subject to error from various factors including surface roughness, soil composition, etc. Soil composition errors can be particularly significant. In an effort to improve accuracy and reduce soil composition error, the so-called "air gap density" method was developed. In this method a measurement is made with the gauge raised above the soil a predetermined height to form an air gap and a reading is obtained based upon both the thickness of the air gap and the density of the top portion of the soil. The air gap measurement can be used in combination with a flush, backscatter measurement to partially cancel out the composition error. Prior measurement methods have not been able to obtain a sufficiently accurate direct measurement of soil density through an air gap. Among other reasons, this is due to the fact that the counts are very sensitive to the size of the air gap. As the size of the gap increases, the count rate increases rapidly, since the soil density becomes a much less significant part of the average density seen by the detector.

In accordance with the present invention the density measurement is taken through an air gap, and means is provided for accurately measuring the air gap during the count and for adjusting the count rate in

accordance with the measured air gap distance to obtain an accurate indication of soil density. The measurement of the air gap distance can be accomplished in various ways in accordance with the broad aspects of the present invention, including the use of ultrasonic means, laser means and capacitance, as well as nuclear methods. The preferred means and method as employed in the embodiment illustrated herein employs ultrasonic methods.

As best seen in Figure 5, the measurement unit 20 comprises a housing 30 having a relatively smooth planar undersurface which is oriented generally parallel and in spaced relation to the pavement surface. The housing 30 encloses a suitable radiation source 31 and a detector means 32. The radiation source may be a CS-137 source of gamma radiation and the detector means may take the form of Geiger-Mueller tubes sensitive to photons. As illustrated, the source 31 is located adjacent to one end of the housing and the detector means 32 is mounted adjacent to the opposite end of the housing. Shielding 34 is provided around the source and around the detector means 32, as is conventional, to prevent radiation from reaching the detector means in a direct path from the source. Additionally, means (not shown) is provided for completely shielding the radiation source when the gauge is not being used for measurement.

As noted earlier, in an air gap measurement technique, the amount of radiation reaching a detector is a function of both the size of the air gap and the density of the material. The attenuation relationship for a single detector means, e.g. for the detector means 32 illustrated may be expressed as follows:

$$CR = A \exp(-BD) - C \qquad (I)$$

where:

CR is the count ratio, the detector count normalized by a standard reference count;

D is the density; and

A,B,C are the usual exponential curve fit parameters for the density vs. count ratio relationship.

The constants A, B, and C are dependent on the size of the air gap between the gauge and the test material. If the air gap is measured, one can come up with relationships for A, B, and C such that:

$$A = a_1 + a_2G + a_3G^2 + a_4G^3$$
$$B = b_1 + b_2G + b_3G^2 + b_4G^3 \qquad (II)$$
$$C = c_1 + c_2G + c_3G^2 + c_4G^3$$

where

A, B, C = constants from density equation I;

a_1, a_2, a_3, a_4 = constants determined by gauge calibration;

b_1, b_2, b_3, b_4 = constants determined by gauge calibration;

c_1, c_2, c_3, c_4 = constants determined by gauge calibration; and

G = Air gap distance between the gauge and the test material.

Knowing the air gap distance, one can calculate A, B, C and then get D from the equation:

$$D = (1/B) \ln (A/(CR + C)) \qquad (III)$$

In the illustrated embodiment of the invention ultrasonic means is utilized for measuring the air gap G between the test material and the measurement unit 20. As shown in Figure 5, the ultrasonic means includes an ultrasonic transmitter 35 and a cooperating ultrasonic

receiver 36 which are mounted in a recessed area or well on the underside of the housing 30 and aimed downwardly for measuring the distance to the underlying pavement surface. Additionally, the ultrasonic means also includes a reference transmitter 37 and cooperating receiver 38 mounted in the recessed well a predetermined distance apart and oriented generally horizontally toward one another for measuring the speed of sound in the air above the heated pavement or other underlying surface and producing a reference signal. This reference signal is utilized by the associated circuitry 54 to compensate for variations in the speed of sound due to changes in air temperature in the measuring region. These components and the associated electronic circuitry which is used in association therewith, as indicated at 54, are commercially available and their selection and use are within the capabilities of persons skilled in this art.

It should be understood that the foregoing description is intended as an illustration of one of a number of possible ways in which a density measurement can be obtained from the detector count data, and persons skilled in the appropriate arts will recognize that other particular solutions are possible within the broad scope and spirit of the present invention. For example, in commonly owned U.S. patent 4,525,854 and in commonly owned copending U.S. patent application Serial No. 681,302 filed December 13, 1984 techniques are disclosed whereby it is possible to obtain density readings which are weighed toward predetermined strata within a test material, and these principles may be utilized for obtaining density measurements in the present invention.

Referring now to Figure 6, the detector 32 is electrically connected with a corresponding amplifier 52. Additionally, as is required, the detector is con-

nected with a source 60 of high voltage. Output from the amplifier 52 is directed to an input/output circuit generally indicated at 62 and is available through such circuitry to an electronic computing device shown in the form of a microprocessor 66 and to display 42. The ultrasonic transmitter 35 and receiver 36 are connected to an ultrasonic driver which provides as an output a signal representative of the air gap distance. This signal is provided to the microprocessor through the input/output circuit 62. Power to the entire device is supplied by a power controller 68.

The microprocessor performs in the circuit of the present invention (as schematically illustrated in Figure 6) a number of functions including governing time intervals for gauging in both "standard" and "measure" modes. The microprocessor also serves the function of a counter and recorder operatively associated with the detector for separately counting and recording the measured radiation information from the detectors and the distance signal from the ultrasonic device. In this regard, the radiation information preferably takes the form of a total radiation count for each Geiger-Mueller detector per time interval. In other embodiments the radiation information may take other forms, such as radiation count rates.

The microprocessor also serves to store, in appropriate form, the instructions needed for converting the amplified radiation counts from detector means 32 into density values and for displaying the density values to the operator. Other functions, generally known to persons appropriately skilled in the art, are performed by the microprocessor.

In the drawings and specification, there has been set forth a preferred embodiment of the invention, and although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation.

THAT WHICH IS CLAIMED IS:

1. A compactor vehicle (10) having rollers (12,13) for compaction of materials sùch as soil, asphalt pavement and the like, said rollers also serving as wheels for the compactor vehicle, a chassis (11) connected to the rollers and adapted for receiving thereon the operator of the compactor vehicle, and motor means for propelling the compactor vehicle along the surface of the material; characterized in that a nuclear density gauge (20,40) is mounted on the compactor vehicle (10) for measuring the density of the material during operation of the compactor vehicle, said gauge comprising a nuclear radiation source (31), nuclear radiation detector means (32) mounted in predetermined spaced relation from said source, and means (24) for suspendingly mounting said source (31) and detector (32) means from said vehicle chassis (11) with the source and detector means being located in spaced relation from the surface of the material so that the source is positioned for emitting nuclear radiation through the air space beneath the gauge means (20) and into the material and the detector means is positioned for detecting backscattered radiation from the material.

2. The invention according to Claim 1 wherein said nuclear density gauge means comprises a measurement unit (20) including a housing, said source (31) and said detector means (32) being located in said housing, and mounting means (22,24) connected to said housing (20) and to the vehicle chassis (11) for suspendingly mounting the housing from the chassis.

3. The invention according to Claim 2 additionally including a control unit (40) mounted on the compactor vehicle (10) at a location accessible to the

operator of the vehicle, said control unit including means (42) for displaying the density reading obtained by said measurement unit (20), and means (21) operatively interconnecting said control unit and said measurement unit.

4. The invention according to Claim 2 wherein said measurement unit (20) includes distance measuring means (35,36) for measuring the spacing of said housing from the surface of the test material.

5. The invention according to Claim 4 wherein said distance measuring means comprises an ultrasonic measuring means.

6. The invention according to Claim 5 wherein the ultrasonic distance measuring means includes means (37,38) to compensate for variations in the speed of sound due to changes in air temperature in the measuring region.

7. The invention according to Claim 2 including means (25,26) cooperating with said measurement unit for raising the measurement unit from its lowered operative suspended position to a retracted non-use position.

8. A compactor vehicle (10) having rollers (12,13) for compaction of materials such as soil, asphalt pavement and the like, said rollers also serving as wheels for the compactor vehicle, a chassis (11) connected to the rollers and adapted for receiving thereon the operator of the compactor vehicle, and motor means for propelling the compactor vehicle along the surface of the material; characterized in that a nuclear density

gauge is mounted on the compactor vehicle (10) for measuring the density of the material during operation of the compactor vehicle, said gauge comprising a control unit (40) mounted on the vehicle chassis (11) at a location accessible to the compactor vehicle operator, a measurement unit (20) operatively connected to said control unit (40) and including a nuclear radiation source (31) and nuclear radiation detector means (32) mounted in predetermined spaced relation from said source, and means (22,24) for suspendingly mounting said measurement unit from the underside of said vehicle chassis (11) with said source (31) and detector means (32) being located in spaced relation from the surface of the material so that the source is positioned for emitting nuclear radiation through the air space beneath the gauge means and into the underlying material and the detector means is positioned for detecting backscattered radiation from the material.

9. The invention according to Claim 8 wherein said measurement unit (20) includes distance measuring means (35,36) for measuring the spacing of the measurement unit (20) from the surface of said material.

10. A compactor vehicle (10) having rollers (12,13) for compaction of materials such as soil, asphalt pavement and the like, said rollers also serving as wheels for the compactor vehicle, a chassis (11) connected to the rollers and adapted for receiving thereon the operator of the compactor vehicle, and motor means for propelling the compactor vehicle along the surface of the material; characterized in that a nuclear density gauge is mounted on the compactor vehicle (10) for

measuring the density of the material during operation of the compactor vehicle, said gauge comprising a measurement unit including

a gauge housing (20);

means (22,24) for suspending said gauge housing (20) from the compactor vehicle (10) in spaced relationship from the surface of the material;

nuclear radiation source means (31) carried by said housing and adapted for emitting gamma radiation from the housing into the underlying air gap between the housing and the material and into the underlying material;

nuclear radiation detector means (32) carried by said housing for detecting photons which have been backscattered from said material,

counter means (62,66) associated with said detector means (32) for obtaining a count of said backscattered photons;

means (35,36) for measuring the distance of said housing from the surface of said material; and

means (66) cooperating with said distance measuring means and with said counter means for correcting said count of backscattered photons to compensate for the effect of the air gap and to thereby obtain the density of the test material.

11. Apparatus for measuring the density of a test material, said apparatus comprising a gauge housing (20); nuclear radiation source means (31) carried by said housing and adapted for emitting gamma radiation from the housing into the underlying test material; nuclear radiation detector means (32) carried by said housing for detecting photons which have been backscattered from said test material, and counter means (66) associated with said detector means for obtaining a count of said backscattered photons;

characterized in that the gauge housing is mounted in spaced relationship from the surface of the test material so that there is provided an air gap between the housing and the test material and the gamma radiation which is emitted from the housing passes through the air gap; and wherein a distance measuring device (35,36) is provided for measuring the distance of said housing from the surface of said test material; and wherein the gauge is provided with means (66) for correcting said count of backscattered photons to compensate for the effect of the density of the air gap and to thereby obtain the density of the test material.

12. Apparatus according to Claim 11 wherein said distance measuring means (35,36) comprises an ultrasonic measuring means.

13. Apparatus according to Claim 12 wherein the ultrasonic distance measuring means includes means (37,38) to compensate for variations in the speed of sound due to changes in air temperature in the measuring region.

14. A method of measuring the density of a test material using a nuclear radiation backscatter gauge (20) including nuclear radiation source (31) and nuclear radiation detector means (32) characterized by

moving the source and detector relative to the test material while maintaining the source and detector in spaced relation above the surface of the test material to form an air gap therebetween,

obtaining a count of the photons which are backscattered to the detector means by the test material,

obtaining a measurement which represents the size of the air gap between the surface of the test material and the detector means, and

correcting said count of backscattered photons based upon the obtained measurement of the air gap to compensate for the effect of the air gap and to thereby determine the density of the test material.

15. A method according to Claim 14 wherein said step of obtaining a measurement of the size of the air gap comprises ultrasonically measuring the air gap.

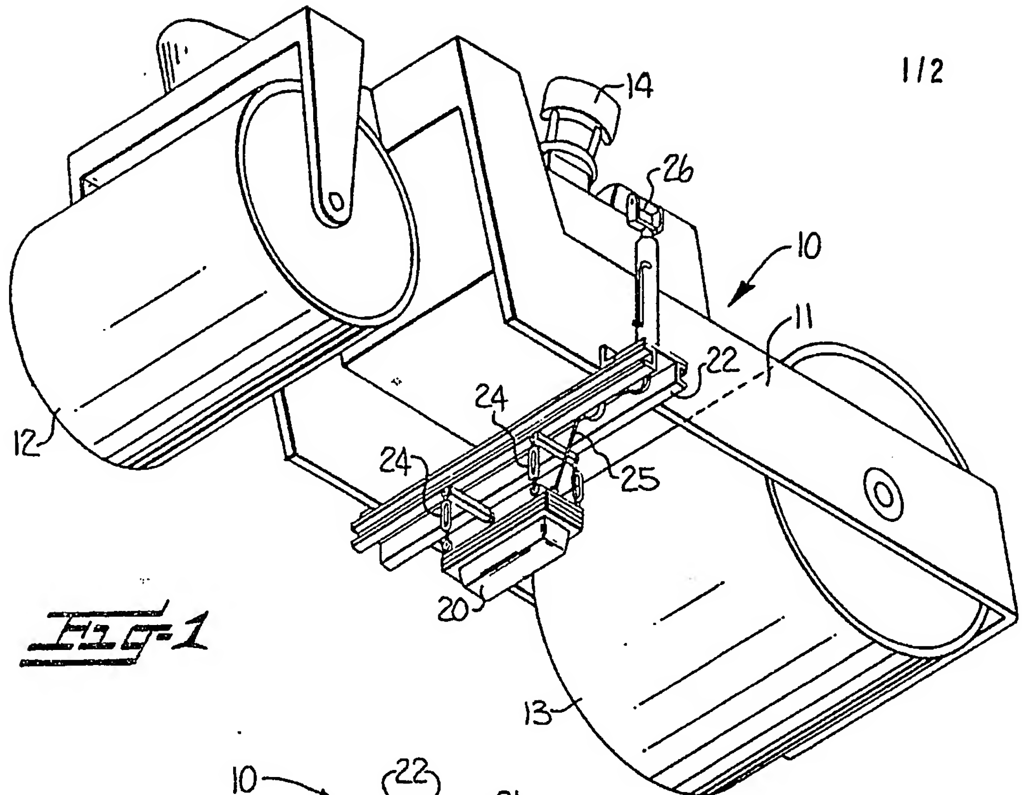

Fig-1

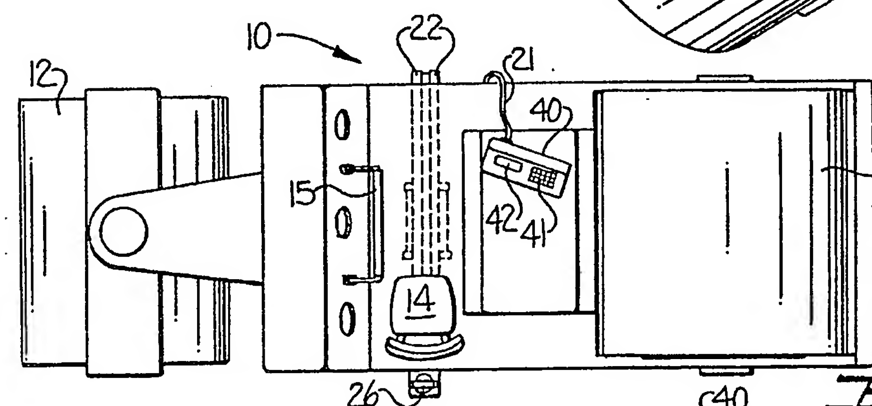

Fig-2

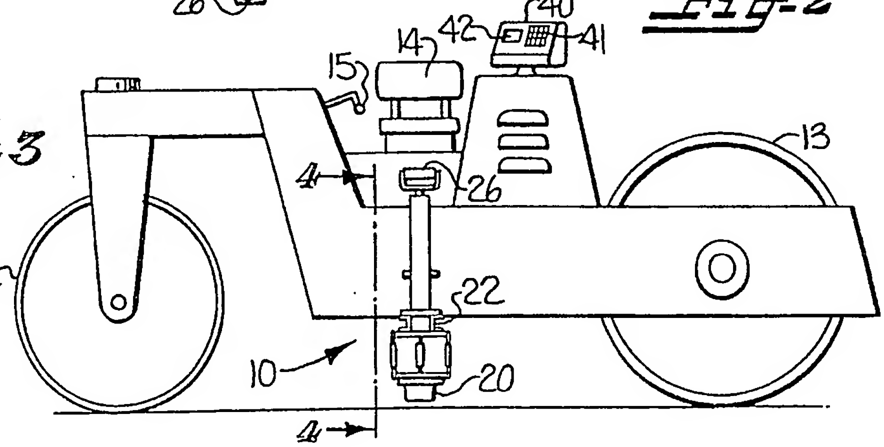

Fig-3

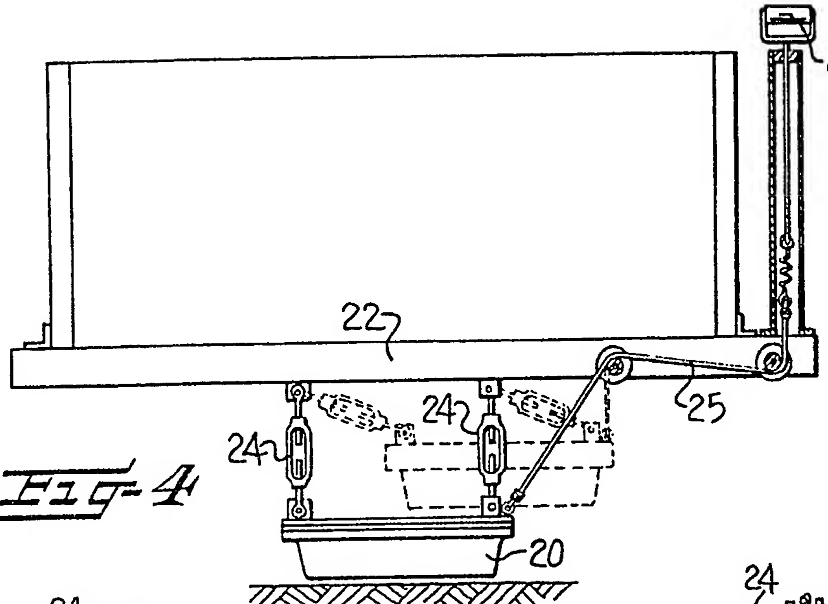

Fig-4

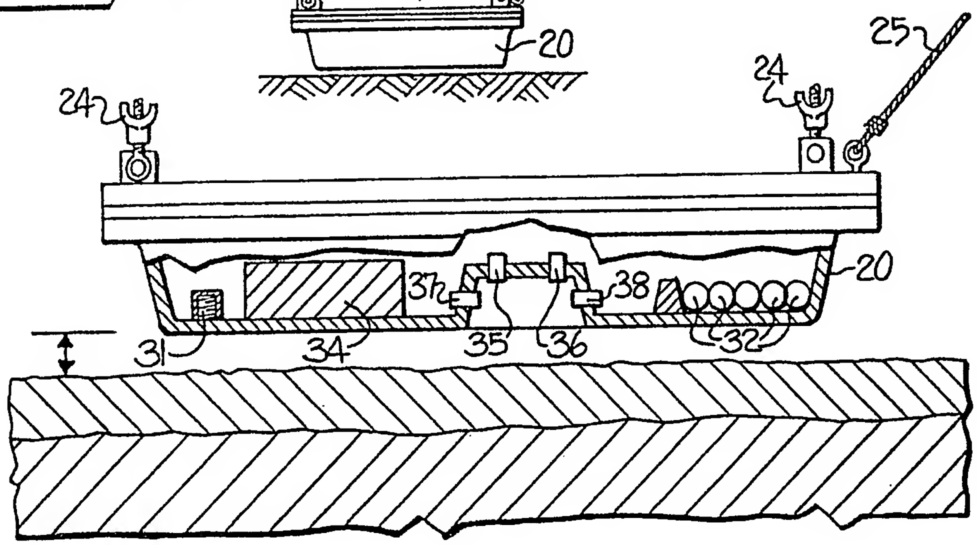

Fig-5

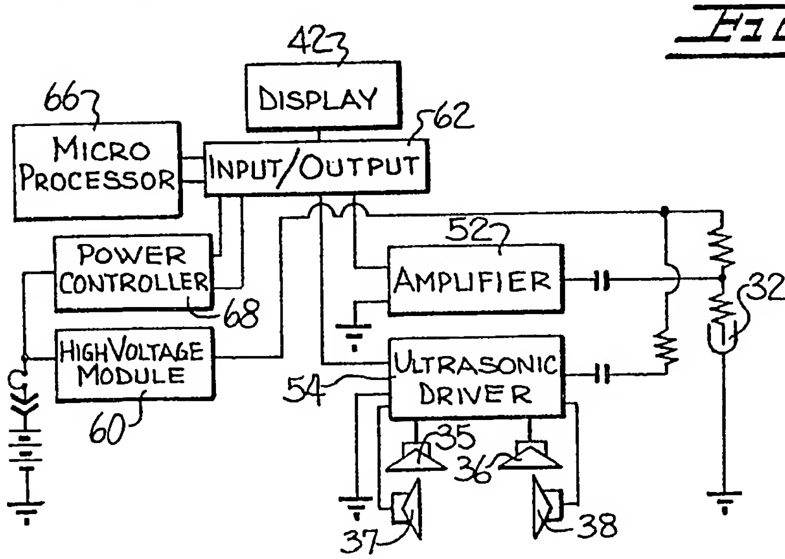

Fig-6